

# **Highly Active Liquid Melts Used To Form Coatings**

## **Cross Reference to Related Applications**

This application claims priority to U.S. Provisional Application No. 60/446,591  
5 filed February 11, 2003.

## **Field of the Invention**

The present invention relates to coatings for metal surfaces, and more particularly  
to coatings that remove surface oxidation as applied. Accordingly, the invention provides  
distributed reducing agents in a metal composition which strategically combine with  
10 surface oxidized layers to provide improved bonding characteristics between the metal  
composition and the oxidized metal surface.

## **Background of the Invention**

All metals except for gold, form native oxide layers which act to passivate the  
15 metal surface. In some metals such as aluminum, the native oxide layer is adherent and  
prevents further corrosive attack of the oxidized surface. However, other materials such  
as iron form a native oxide layer which is nonadherent and spalls off leaving base metal  
susceptible to further oxidation, i.e., rusting. The tendency of metals to form native oxide  
layers is very strong due to the high thermodynamic stability of the resulting oxide which  
20 forms. When virgin metal surfaces are exposed to oxygen containing atmospheres,  
generally the native oxide layer grows to its full thickness in a short time and for very  
reactive metals such as aluminum, or chromium, either as a metal or when dissolved in  
stainless steel, the oxidation can occur in a few seconds. Even in experiments done at

high vacuum such as  $10^{-9}$  torr, virgin metal surfaces of these reactive metals will quickly form native oxide layers.

Unfortunately, the chemical bonding nature of metals is such that metallic materials typically do not bond well to ceramic materials, including metal oxides such an oxidized metal surface, which are formed including ionic bonds. This poor bonding is a function of the incompatible nature of the metallic bonds, which may be modeled as ion cores surrounded by a sea of shared free electrons, and ionic bonds which result from directional electron transfer from specific cation atoms to specific anion atoms.

The tendency of metals to form oxides on the surfaces thereof, and the incompatibility of metal to ceramic bonding presents serious obstacles in the field of metal coatings. For example, in thermal spraying of metal coatings, it is often very difficult to bond the metal coating to reactive metals or alloys such as stainless steel alloys, aluminum alloys, and refractory alloys such as tungsten, zirconium, and titanium. Even if the base reactive metal is degreased and subsequently grit blasted to expose virgin metal surface, the native oxide layer reforms at a very fast rate, before thermal deposition of coating can begin. To try to overcome this, often coupon preparation and subsequent spraying is done at high vacuum in a vacuum chamber. This adds considerable expense to the coating operation, and is only marginally effective for highly reactive metals.

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### **Summary of the Invention**

A metallic alloy for coating a metal surface comprising a deoxidizing element, or a combination of deoxidizing elements, wherein said deoxidizing element reduces a metal-oxide layer on said metal surface. In method form, the present invention relates to

a method of forming a metallic coating on a metal surface comprising providing a metallic coating alloy comprising a deoxidizing element, or combination of deoxidizing elements, melting said metallic coating alloy to a liquid state, or partially liquid state and applying said liquid melt of said metallic coating alloy to said metal surface. In a further process embodiment the present invention relates to a method of forming a metallic coating on a metal surface comprising, providing a metallic coating alloy comprising a deoxidizing element, melting said metallic coating alloy to a liquid state, applying said liquid melt of said metallic coating alloy to said metal surface wherein said metal surface contains an oxidized surface layer, reducing said oxidized surface layer; and forming a metallurgical bond at said location where said oxidized surface layer has been reduced by said deoxidizing element.

### **Brief Description of the Drawings**

The invention herein is disclosed in part with reference to preferred and exemplary embodiments, which description should be understood in conjunction with the accompanying figures, wherein:

Figure 1 is a chart graphically illustrating bond strength as a function of substrate material and coating thickness for coatings applied using high velocity oxy-fuel spraying technique.

### **Description Of The Preferred Embodiments**

According to a first aspect, the present invention is directed at a metallic alloy suitable for coating metal surfaces. The metallic alloy may form a highly active liquid melt that may be reactive with and remove surface oxidation of metal substrates to be

coated. The metallic alloy preferably includes combinations of active oxide forming/deoxidizing elements. Exemplary active elements may include manganese, chromium, silicon, carbon, and boron.

According to another aspect of the invention is a method of coating a metal surface including applying to a metal surface a melt containing a coating metal alloy and at least one oxide forming/deoxidizing element. Applying the melt may include wire-arc spraying, plasma spraying, high velocity oxyfuel spraying, flame spraying, and similar application techniques. The oxide forming/deoxidizing element may include, for example, manganese, chromium, silicon, carbon, and boron.

The present invention is directed at activated liquid melts containing a selected fraction of deoxidizing, i.e., oxygen seeking elements. More generally, these elements may be classified as reducing agents. Such liquid melts therefore enhance the ability of the metallic coatings to bond to metals that have oxidized surface characteristics. The presence of the deoxidizing additive serves to interact with the oxidized surface features, which is important since the oxidized surface features operate to reduce bonding strength.

When the highly activated liquid melt contacts a native oxide layer of a metal, the native oxide may be reduced, thereby removing the oxygen from the surface of the base metal. This allows a metallic alloy melt to form with a higher relative degree of metallurgical bonds to the base metal of the coupon, part, device, or machine to be coated. By metallurgical bonds it is in reference to a metallic chemical bonding mechanism, as compared to a physical bonding (mechanical interaction due to surface irregularities). Accordingly, this ability to form relative higher amounts of metallurgical bonds as well as physical/mechanical bonds between the base metal of a reactive alloy and a coating allows more effective coating of such metals. Additionally, coating

processes utilizing activated liquids consistent with the present invention allow the formation of high bond strengths to metals such as iron and steels.

Consistent with the present invention, specially designed alloy melts containing combinations of oxide forming/deoxidizing transition metals including manganese (Mn),  
5 chromium (Cr), vanadium (V), titanium (Ti), zirconium (Zr), hafnium (Hf), niobium (Nb), tantalum (Ta), aluminum (Al), and the lanthanide metals (Lanthanum>>Lutetium) in combination with oxygen seeking nonmetals/metalloids such as silicon (Si), carbon (C), boron (B), phosphorous (P), and sulfur (S) which may all be used in coating processes. Desirably, the liquid melt may be provided having selected fractions of the  
10 deoxidizing alloying elements. The fraction of deoxidizing elements is between 5 and 70 percent, and all increments therebetween.

The liquid melt containing such fractions of the deoxidizing elements generally have a low tendency to form compounds between the alloying ingredients, thereby preserving their ability to reduce the oxides on a given substrate. Additionally, in a  
15 preferred embodiment of the invention no primary precipitates form employing such deoxidizing elements in the liquid melt. Thus, in the preferred case, the entire fraction of deoxidizing elements remain dissolved in the alloy melt, and alloy melt that is formed retains a high activity and affinity for oxygen. However, it should be understood that liquid melts consistent with the present invention may form small amounts of primary  
20 precipitates that will result in a reduction in the overall activity of the liquid melt.

The high activity liquid melts may be formed during the actual process of forming a coating on a substrate, including when powder or wire become molten as it passes through a plasma, high velocity oxyfuel (HVOF), flame spray, or wire-arc thermal spray system. These activated melts may be directed toward/applied to a surface of a metal that

is to be coated. As the melt is applied to the oxidized surface of the metal to be coated, the surface is scrubbed clean of its native or residual oxide layer due, at least in part, to the presence of selected concentrations of unbound oxide forming elements. The relatively clean metal surface may then be susceptible to receipt of a metallic coating that  
5 may be bound to the metal surface via a combination of strong metallurgical bonds, along with the conventional but weaker physical/mechanical bonds.

The scrubbing/deoxidizing action provided by the activated liquid melts may even allow spraying relatively strongly bound coatings onto metal surfaces that are usually very difficult to bond to, including stainless steel alloys, aluminum alloys, and refractory  
10 metals such as tungsten, zirconium and titanium.

### **Experimental Examples**

Exemplary coating alloys were produced including highly active materials consistent with the present invention, including Super Hard Steel™ coating compositions which are an iron based glass forming alloys that exhibit extreme hardness when  
15 processed by various methods into high performance coatings.

Bond strength tests were conducted using two types of feedstock. First, a high velocity oxy-fuel sprayed coating was provided to a substrate using an atomized powder having a composition of 60.1 wt% iron, 2.3 wt% manganese, 20.3 wt% chromium, 4.9 wt% molybdenum, 6.4 wt% tungsten, 3.6 wt% boron, 1.0 wt% carbon, and 1.4 wt%  
20 silicon and a nominal particle size in the range of 22 to 53 microns. Second, a wire-arc sprayed coating was applied to a substrate using a cored wire having a 1/16 inch diameter and a composition of 68.0 wt % iron, 23.2 wt% chromium, 1.2 wt% molybdenum, 1.5 wt% tungsten, 3.6 wt% boron, 0.9 wt% carbon, 0.7 wt% silicon, and 0.8 wt% manganese.

Bond strength testing was conducted consistent with ASTM c633. The results of the bond strength testing are provided in Table 1 below.

**Table 1 Summary Of Bond Strength Data (ASTM c633)**

Spray Method	substrate	thickness	Bond strength (psi)	Failure Mode
HVOF	carbon steel	40 mil	14307	Adhesive Failure
HVOF	carbon steel	40 mil	13864	Adhesive Failure
HVOF	carbon steel	40 mil	13591	Adhesive Failure
HVOF	316 stainless steel	40 mil	13958	Adhesive Failure
HVOF	316 stainless steel	40 mil	14502	Adhesive Failure
HVOF	316 stainless steel	40 mil	13368	Adhesive Failure
HVOF	aluminum	40 mil	13132	Adhesive Failure
HVOF	aluminum	40 mil	12436	Adhesive Failure
HVOF	aluminum	40 mil	13205	Adhesive Failure
HVOF	carbon steel	110 mil	12738	Coating Failure - bottom Adhesive Failure 60% - Coating break 40%
HVOF	carbon steel	110 mil	13059	Adhesive Failure 60% - Coating break 40%
HVOF	carbon steel	110 mil	12052	Coating break 40%
Wire Arc	carbon steel	40 mil	11199	Coating Failure - middle
Wire Arc	carbon steel	40 mil	11396	Coating Failure - middle
Wire Arc	carbon steel	40 mil	10386	Coating Failure - middle
Wire Arc	316 stainless steel	40 mil	9562	Coating Failure - middle
Wire Arc	316 stainless steel	40 mil	9643	Coating Failure - middle
Wire Arc	316 stainless steel	40 mil	9530	Coating Failure - middle
Wire Arc	aluminum	40 mil	5492	Coating Failure - middle
Wire Arc	aluminum	40 mil	5501	Coating Failure - middle
Wire Arc	aluminum	40 mil	6461	Coating Failure - middle

5 From the reported data above, it can be seen that with HVOF spraying, the bond strength does not appear to change as a function of substrate material, i.e. carbon steel, stainless steel, or aluminum. Additionally, there is only very limited decreases in bond strength on increasing coating thickness from 40 mil to 110 mil in thickness. However, when spraying the coating using wire-arc, there is found to be a reduction in bond

strength depending on the substrate material. However, even the lower 5500 to 6500 psi bond strength realized when the coating is applied to an aluminum substrate is very good compared to other wire-arc alloys sprayed onto aluminum. The data collected using high velocity oxy-fuel spraying is graphically presented in Figure 1.

5        The collected values of bond strength are remarkable for several reasons. First, ASTM C633 standard requires that the coating be a minimum of 0.015 inches in thickness and most tests are carried out on coatings sprayed to thicknesses that are very close to this minimum because as the coating becomes thicker the chance of developing a critical flaw in the coating leading to premature failure is much greater. Second, the  
10 results of the tests were remarkable because, when failure of the coating was observed, the coating generally failed due to a critical flaw arising from the spray process. Thus, the failure of the coatings, when failure was found, did not generally occur at the coating/metal substrate interface, indicating an extremely effective metallurgical metal to metal bond which is formed as a result of the cleansing of the native oxide layer of the  
15 substrate. Such effect had not previously been observed with thermal spray coatings. Finally, the magnitude of the bond strength of the high velocity oxy-fuel coatings (12,000 to >14,000 psi) is exceptional for metallic coatings, and is even superior to the bond strength of materials that are specifically used as intermediate bond coats, such as 75B Nickel Aluminides that generally provide bond strengths in the range of about 7,000 psi.